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Regional analysis of dynamic deformation characteristics of native aortic valve leaflets

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A B S T R A C T

Background: The mechanical environment of the aortic valve (AV) has a significant impact on valve cellular biology and disease progression, but the regional variation in stretch across the AV leaflet is not well understood. This study, therefore, sought to quantify the regional variation in dynamic deformation characteristics of AV leaflets in the native mechanical environment in order to link leaflet stretch variation to reported AV calcification patterns.

Methods: Whole porcine AVs ($n=6$) were sutured into a physiological left heart simulator and subjected to pulsatile and physiologically normal hemodynamic conditions. A grid of ink dots was marked on the entire ventricular surface of the AV leaflet. Dual camera stereo photogrammetry was used to determine the stretch magnitudes across the entire ventricular surface over the entire diastolic duration.

Results: Elevated stretch magnitudes were observed along the leaflet base and coaptation line consistent with previously reported calcification patterns suggesting the higher mechanical stretch experienced by the leaflets in these regions may contribute to increased disease propensity. Transient stretch overloads were observed during diastolic closing, predominantly along the leaflet base, indicating the presence of a dynamic fluid hammer effect resulting from retrograde blood flow impacting the leaflet. We speculate the function of the leaflet base to act in cooperation with the sinuses of Valsalva to dampen the fluid hammer effect and reduce stress levels imparted on the rest of the leaflet.

1. Introduction

The aortic valve (AV) is a dynamic structure exposed to a harsh mechanical environment of transvalvular pressure, cyclic flexure, and axial, bending and shear stress (Sacks and Yoganathan, 2007; Stella et al., 2007; Thubrikar, 1990). It is well documented that the mechanical environment significantly impacts valve cellular biology and is thought to contribute to AV disease onset and progression (Liu et al., 2007; Otto, 2008), though the biomechanical mechanisms are yet to be clearly defined. Altered or non-physiological stretch levels in AV leaflets have been shown to trigger patho-biological responses consistent with calcific AV disease (Balachandran et al., 2006, 2009; Merryman et al., 2007). Comprehensive characterization of the native AV leaflet stretch distribution, therefore, may provide a link to explain the observed leaflet calcification patterns and help to more accurately define the mechanism of AV disease pathogenesis.

Characterization of strain mechanics of the native aortic valve has been undertaken by several authors (Adamczyk and Vesely, 2002; Billiar and Sacks, 2000; Christie and Barratt-Boyes, 1995; Stella and Sacks, 2007; Vesely and Noseworthy, 1992). However, these studies were all conducted on partial valve explants or other idealized setups rather than using the whole aortic root in its native mechanical environment, thus it is unclear how the results of such studies translate to native valve characteristics. To characterize AV mechanics in the native AV environment, our group investigated the time-varying stretch characteristics of specific points of the aortic valve using an *in-vitro* valve model (Yap et al., 2010). Native aortic valve leaflet stretch was characterized over the entire cardiac cycle, but the study was limited to reporting only one localized stretch value for the leaflet per time point, and did not provide spatial stretch information over the leaflet surface. The local mechanical environment of different leaflet regions could vary significantly, and such regional variations in mechanical properties could explain the reason for localization of AV calcification patterns at specific regions of the leaflet: the base and along the line of cusp coaptation (Thubrikar et al., 1986). To date, however, no studies have reported on

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